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(21) International Application Number: PCT/EP99/01397 (22) International Filing Date: 4 March 1999 (04.03.99) (30) Priority Data: 60/077,023 6 March 1998 (06.03.98) US (71) Applicant (for all designated States except CA): SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ B.V. [NL/NL]; Carel van Bylandtlaan 30, NL-2596 HR The Hague (NL). (71) Applicant (for CA only): SHELL CANADA LIMITED [CA/CA]; 400 - 4th Avenue S.W., Calgary, Alberta T2P 2H5 (CA). (72) Inventor: SMITH, David, Randolph; 861 White Oak Drive, Bellville, TX 77418 (US).		(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG). Published <i>With international search report.</i> <i>Before the expiration of the time limit for amending the</i> <i>claims and to be republished in the event of the receipt of</i> <i>amendments.</i>
(54) Title: INFLOW DETECTION APPARATUS AND SYSTEM FOR ITS USE		
(57) Abstract There is provided a method for monitoring fluid flow within a region to be measured of a subterranean formation, said method comprising placing at least one source within said subterranean formation; placing at least one sensor within said region to be measured, wherein each said at least one sensor is adjacent to at least one source such that said sensor measures changes to said fluid caused by said source; and providing at least one means for transmitting data from each said at least one sensor to at least one data collection device, said at least one data collection device capable of communicating with an operator.		

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INFLOW DETECTION APPARATUS AND SYSTEM FOR ITS USE

Field of the Invention

This invention relates to a method for measuring fluid flow in a subterranean formation; in particular measurements of flow rates of liquids, gases, and mixed fluids in subterranean formations.

Background

Recent developments in the oil drilling industry of well bore construction techniques such as horizontal wells and multi-lateral wells, present new challenges to the completion and reservoir engineering disciplines. High rate horizontal wells in deep water conditions further push the technology tools the petroleum engineer has available to safely and prudently produce the reservoirs.

Classical methods of reservoir monitoring assume the permeability ("K") and height ("H") of the zone contributing to the production of the well is known. This "KH" is often confirmed with production logs on a periodic basis and is typically considered constant. The KH of a well is paramount for most reservoir calculations. In a horizontal well or a multi-lateral well, the H of the well bore penetrating the reservoir is known from electric logging methods, and more recently by logging while drilling techniques. However, the logged reservoir interval may not be the same as the H actually contributing to the well production and, in fact, the H may change with time.

The industry has adopted a laze faire attitude relating to the assumption of inflow performance in horizontal and multi-lateral wells. Grand assumptions regarding inflow well performance are made based on

surface data (i.e. flow rates, pressures, water cut, etc.), possible down hole pressure gauges, and rules of thumb. The reality is that these assumption can lead to poor well performance, poor reservoir management, completion equipment failures, and in the worst cases, catastrophic failure of the well.

The only method currently available to the reservoir or production engineer to monitor changes or losses in "H" is to run a wire line or tubing deployed production log during well interventions. These logs are difficult to interpret, particularly in horizontal and high angle wells. This is due to the flow meters inability to measure the 3 phase flow rates, often referred in the literature as water hold up or gas blow by. This procedure of production logging requires a rig mobilization, resulting in lost production during the rig up and rig down of the logging equipment, and presents a risk of loosing equipment in the well. Production logging is not always possible (e.g. some subsea completions or wells in which an electrical submersible pump (ESP) is installed). Moreover, since the production logging data is subject to interpretation, the decision to run the production-logging suite is often avoided. The end result is that the production is maintained by increasing the choke size at the surface. This can result in more damage, and ultimately in screen and well bore failures or large hydrate production and blowouts.

Summary of the Invention

The method of the invention provides a means for monitoring fluid flow directly within a region to be measured of a subterranean formation, said method comprising:

placing at least one source within said subterranean formation;

placing at least one sensor within said region to be measured, wherein each said at least one sensor is adjacent to at least one source such that said sensor measures changes to said fluid caused by said source;

5 providing at least one means for transmitting data from each said at least one sensor to at least one data collection device, said at least one data collection device capable of communicating with an operator.

10 There is also provided a method for monitoring fluid flow in a region to be measured of a well bore, while the well bore is on-line, said method comprising:

placing at least one source selected from a thermal source, an acoustic source, and combinations thereof within said region to be measured;

15 placing at least one sensor selected from a thermal sensor, an acoustic sensor, and combinations thereof within said region to be measured, wherein each said at least one sensor is adjacent to at least one source such that said sensor measures changes to said fluid caused by said sources;

20 providing at least one means for transmitting data from each said at least one sensor to at least one data collection device, said at least one data collection device capable of communicating with an operator.

25 Detailed Description

The method of the invention provides a means for monitoring the flow of fluid, wherein fluid means liquids or gases or mixtures of liquids and gases, from subterranean formations. Measurement takes place directly in the region where a measurement is desired. In the case of a flowing well, the measurements may be taken while the well is producing. Thermal and/or acoustic sources are placed in the fluid flow path and sensors capable of detecting temperature or acoustic

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changes placed near the sources detect changes to the fluid caused by the sources.

One embodiment of the invention provides a method for monitoring fluid flow within a region to be measured of a subterranean formation. At least one source is placed within the formation. Placement is relatively permanent, meaning the source is set and then left in the measurement zone. At least one sensor is also placed within the region to be measured. Each sensor should be adjacent to one or more sources, in close enough proximity to measure changes to the fluid caused by the source(s). It is necessary to also provide at least one means for transmitting data from the sensors to at least one data collection device. The data collection device may be subterranean, on the surface, or in the air but it must be capable of communicating with an operator. As used herein, an operator may be an object, such as an operating station, or a human.

The sources may be optical sources, electrical heat sources, acoustic sources, or combinations thereof. Examples include thermistors, optical heaters, continual heating elements, electric cables, sonar generators, and vibration generators. Because it is optimum to limit restrictions in the formation, the preferred sensors are optical fibres, which are small enough to be non-intrusive. The optical fibres may also act as the data transmission means, thereby serving two purposes. The sources and the sensors are preferably oriented perpendicular to the fluid flow.

When the subterranean formation is a well, the fluid flow region to be measured is typically within the well bore, be it vertical, horizontal or deviated. A means for deploying the sensors and data links in a fairly non-intrusive manner is via hollow tubular members.

The system of the invention is expected to perform well using applied well technology known as Micro Optical Sensing Technology ("MOST"). MOST allows for the miniaturization of sensing equipment in submersible equipment. Fundamentally, oil and gas well environments have restricted geometry and hostile conditions of temperature and pressure. MOST is able to function in these environments due to it's ability to use very small diameter data links (optic fibres) and to use sensors that can withstand temperatures above 200 °C.

Since the sources, sensors and data links are permanently installed in the desired region of the formation, there is no need for well interventions, such as production logging. The method can provide a continual inflow performance profile of the formation on a real time basis and multiple flow detection nodes along the formation can be monitored.

The use of thermal sources and sensors will be used as an example. A series of electrically or optically powered heat sources may be placed along a well bore axis parallel to a series of thermal sensors. The thermal sources may be in many forms, including but not limited to single point heating elements like thermisters, optical heaters, or a continual heating element like electric cable.

The heat sensors are preferably single or multiple optic fibres. The fibres may be deployed into the well in multiple means and in multiple geometry. An example of deployment which will protect the fibres from hydrogen exposure is to arrange the temperature sensors and data links in small hollow members, such as tubes. The flow detection system is formed by placing the optic fibres in the flow stream before the heaters, after the heaters, or both. Other embodiments uses the optic fibres and heaters deployed parallel to one another, surrounding one

another in coil configurations, and many other geometry's. The preferred embodiment places the heat source and thermal sensors perpendicular to the fluid flowing in the well bore, such that the heat source heats the fluid while the thermal sensors measure the heat change in the fluid stream flowing over the heat source. This system then forms a series of classic thermal flow meters according to the following simplified heat flow equation:

$$Q = Wc_p (T_2 - T_1)$$

where

Q = heat transferred (BTU/Hr);

W = mass flow rate of fluid (lbm/Hr); and

c_p = specific heat of fluid (BTU/lbm °F).

The accuracy of the flow meter is dependent on the accuracy of specific heat data for the flowing fluids. The specific heat of the fluids in the well will change with time, flowing pressures, and reservoir conditions (e.g. coning).

Optimum well production requires the heat sources and temperature measurement devices to be small and non-intrusive to the well bore inside diameter. Non-intrusive deployment allows for the well to be fully opened and thus allows for stimulation, squeeze, or logging techniques to be performed through the completion with the sources, sensors and data links permanently installed.

The preferred sensors and/or data links of the invention are optic fibres. Optic fibres are exotic glass fibres which are available with many different coatings and by various different manufacturing methods that affect their optical characteristics. Optic fibres have a rapid decrease in functionality when exposed to hydrogen, and of course subterranean water is a readily available hydrogen carrier. Therefore the fibres must be

placed in a carrier. But other characteristics of optic fibres allow one fibre to read multiple changes along the fibre's length, an obvious advantage.

5 Fibers may be used in oil and gas wells in
conjunction with Optical Time Delay Reflectometry
("OTDR") devices (commonly referred to as "intrinsic
measurement"). Intrinsic sensing along the fibre is done
with application of quantum electrodynamics ("QED"). QED
relates to the science of sub-atomic particles like
10 photons, electrons, etc. For this application, interest
is in the photons travelling through a very special glass
sub-atomic matrix. The probability, or probability
amplitude, of the photon interacting with a silicon
dioxide sub atomic structure is known for each
15 specialized optic fibre. The resulting back scattering
of light as a function of thermal affects in the glass
subatomic structure has a very well known relationship to
the index of refraction of the optic fibre. Knowledge of
the power and frequency of the light being pumped, or
20 launched down the optic fibre allows for calculation of
the predicted light and frequency emitted or back
scattered at a given length along the optic fibre.

 The process of the invention uses OTDR and thermal
and/or acoustic sources to measure flow in wells. Flow
25 changes at each node may be monitored versus time,
providing a qualitative measurement on a permanent basis
in real time. Knowing the glass and laser light being
used, a back scattering returning power can be measured
with "OTDR" according to the following equation:

30
$$P_{bs}(l) = \frac{1}{2} P_0 \Delta t v_g C_s N A^2 \exp (-2\alpha dx)$$

where

P_{bs} = backscattering power returning from distance l ;

P_0 = launch power;

Δt = source time pulse width, in time units;

v_g = group velocity;

C_s = scattering constant;

NA = numerical aperture of fibre; and

α = total loss of attenuation coefficient.

5 OTDR can successfully and very repeatably measure the back scattering changes as a function of temperature caused by a laser pulsed light wave down an optic fibre, by relating C_s to and α .

$$C_s \cong (\alpha_r)_{co} + (\alpha_s)_{co} + P_c/P_t (\alpha_s)_d$$

10 and

$$\alpha = \alpha_{co} + P_c/P_t (\alpha_d)$$

where

α_r = Raman scattering coefficient;

α_s = Rayleigh scattering coefficient;

15 $()_{co}$ = parameter associated with fibre core;

$()_{cl}$ = parameter associated with fibre cladding; and

P_{cl}/P_{total} = ratio of total power exists in cladding due to evanescent wave effects.

20 The OTDR equipment uses a laser source, an optic fibre; a directional coupler connected to the fibre, an optoelectronic receiver, signal processing, and data acquisition equipment.

25 The method of the invention allows simple actions to be performed downhole without surface intervention, and allows reservoir performance downhole to be monitored using 4D seismic and other technologies. The present invention may also be applied to other flow processes (i.e. pipelines, refining processes, etc.). It will be apparent to one of ordinary skill in the art that many changes and modifications may be made to the invention
30 without departing from its spirit or scope as set forth herein.

C L A I M S

1. A method for monitoring fluid flow within a region to be measured of a subterranean formation, said method comprising:
 - placing at least one source within said subterranean formation;
 - placing at least one sensor within said region to be measured, wherein each said at least one sensor is adjacent to at least one source such that said sensor measures changes to said fluid caused by said source;
 - providing at least one means for transmitting data from each said at least one sensor to at least one data collection device, said at least one data collection device capable of communicating with an operator.
2. A method according to claim 1 wherein said source is selected from an optical source, an electrical heat source, an acoustic source, and combinations thereof.
3. A method according to claim 2 wherein said source is selected from a thermister, an optical heater, a continual heating element, an electric cable, a sonar generator, a vibration generator, and combinations thereof.
4. A method according to claim 1 wherein said sensor is one or more optical fibres.
5. A method according to claim 1 wherein said one or more sensor and said one or more source are oriented perpendicular to said fluid flow.
6. A method for monitoring fluid flow in a region to be measured of a well bore, said method comprising:
 - placing at least one source selected from a thermal source, an acoustic source, and combinations thereof within said region to be measured;

5 placing at least one sensor selected from a thermal sensor, an acoustic sensor, and combinations thereof within said region to be measured, wherein each said at least one sensor is adjacent to at least one source such that said sensor measures changes to said fluid caused by said sources;

10 providing at least one means for transmitting data from each said at least one sensor to at least one data collection device, said at least one data collection device capable of communicating with an operator.

7. A method according to claim 6 wherein said source is selected from an optical source, an electrical heat source, an acoustic source, and combinations thereof.

15 8. A method according to claim 7 wherein said thermal source is selected from a thermister, an optical heater, a continual heating element, an electric cable, a sonar generator, a vibration generator, and combinations thereof.

20 9. A method according to claim 6 wherein said sensor is one or more optical fibres.

10. A method according to claim 9 wherein said sensors and data links are deployed in hollow tubular members.

25 11. A method according to claim 6 wherein said one or more sensor and said one or more source are oriented perpendicular to the fluid flow in said region to be measured of said wellbore.

INTERNATIONAL SEARCH REPORT

International Application No

PCT/EP 99/01397

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 E21B47/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 E21B G01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 442 188 A (TEXACO DEVELOPMENT CORP) 21 August 1991	1-3,6,7
Y	see abstract see page 2, column 1, line 1 - line 21 see page 3, column 3, line 32 - column 4, line 30; claim 1	4,9,11
X	EP 0 481 141 A (TEXACO DEVELOPMENT CORP) 22 April 1992 see abstract see page 2, column 1, line 1 - line 35 see page 2, column 2, line 4 - line 10 see page 3, column 3, line 42 - column 4, line 31; claims 1,2	1-3,6,7
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Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	FR 2 707 697 A (FIS) 20 January 1995 see page 2, line 30 - page 3, line 23 see page 6, line 20 - page 7, line 11; claims 1,2; figure 4B ----	1-3,5 11
Y	EP 0 508 894 A (SCHLUMBERGER LTD ;SCHLUMBERGER TECHNOLOGY BV (NL); SCHLUMBERGER HO) 14 October 1992 see abstract see page 2, column 1, line 1 - line 11 see page 2, column 2, line 20 - line 36 see page 3, column 4, line 37 - line 54; claims 4,7,9-11 ----	4,9
A	US 5 208 650 A (GIALLORENZI THOMAS G) 4 May 1993 see column 1, line 5 - line 13 see column 2, line 50 - line 56; claims 1-3 ----	8
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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EP 0481141 A	22-04-1992	US 4982383 A DK 481141 T	01-01-1991 03-10-1994
FR 2707697 A	20-01-1995	NONE	
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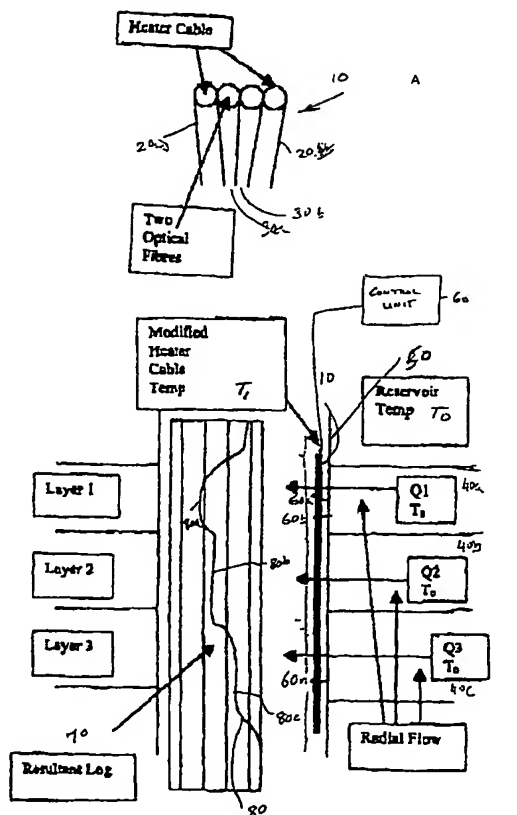
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(21) International Application Number: PCT/US99/19781 (22) International Filing Date: 25 August 1999 (25.08.99) (30) Priority Data: 60/097,783 25 August 1998 (25.08.98) US (71) Applicant (for all designated States except US): BAKER HUGHES INCORPORATED [US/US]; Suite 1200, 3900 Essex Lane, Houston, TX 77027 (US). (72) Inventors; and (75) Inventors/Applicants (for US only): WILLIAMS, Glynn [GB/GB]; Roman House, Northway, Walworth Industrial Estate, Andover, Hampshire SP10 5QD (GB). NEUROTH, David, H. [US/US]; 18305 South 4185 Road, Claremore, OK 74017 (US). DALRYMPLE, Larry, Verl [US/US]; 5650 S.E. Roden Road, Claremore, OK 74017 (US). (74) Agents: ROWOLD, Carl, A. et al.; Baker Hughes Incorporated, Suite 1200, 3900 Essex Lane, Houston, TX 77027 (US).		(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG). Published With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.	

(54) Title: METHOD OF USING A HEATER WITH A FIBER OPTIC STRING IN A WELLBORE

(57) Abstract

The present invention provides a heater cable (10) that may be deployed in a wellbore to elevate the temperature of the wellbore above the temperature of the surrounding fluid and the formation. One or more fiber optic strings are included in or are carried by the heater cable. The heater cable carrying the fiber optics is placed along the desired length of the wellbore. At least one fiber optic string measures temperature of the heater cable at a plurality of spaced apart locations. Another string may be utilized to determine the temperature of the wellbore. In one aspect of this invention, the heater cable is heated above the temperature of the wellbore. The fluid flowing from the formation to the wellbore lowers the temperature of the cable at the inflow locations. The fiber optic string provides measurements of the temperature along the heater cable. The fluid flow is determined from the temperature profile of the heater cable provided by the fiber optic sensors.



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METHOD OF USING A HEATER WITH A FIBER OPTIC STRING IN A WELLBORE

1. Field of the Invention

This invention relates to utilizing fiber optic sensor strings with heater cables for use in oil wells and more particularly for determining the flow of formation fluid into the wellbore and to control the operation of the heater cables for optimum operations.

2. Background of the Art

Heater cables are often used in wellbores to increase the temperature of the fluid in the wellbore to prevent the formation of paraffins and to prevent the oil from flocculating. Such phenomena cause at least some of the oil to become highly viscous, and often plugs the perforations. Such fluids can clog the electrical submersible pumps. Heater cables are also used to heat the formation surrounding the wellbores which contain heavy (highly viscous) oil to reduce the viscosity of such oil.

The heater cable usually is a resistance heating element. High current supplied from the surface can heat the cable to a temperature substantially higher than the formation temperature. In ESP applications, a heater current

may be deployed below the ESP. In other production wells, heater cable may be installed along any desired portion or segment of the wells. It is desirable to determine the fluid flow from various production zones along a wellbore and to monitor and control the temperature of the heater cable so as to heat the wellbore only as required for optimum recovery and to reduce power consumption.

U.S. Patent 4,435,978 discloses a hot wire anemometer in which heat is supplied at a constant rate to a sensor element with fluid flowing past the element. The drop in temperature of the sensor element is used to give a measurement of the fluid flow. This method accurately measures the flow under a variety of flow conditions.

U.S. Patent Ser. No. 5,551,287 discloses a wireline device in which a hot film anemometer deployed on sensor pads measures the temperature of fluid entering the borehole. The fluid flowing past the sensor element produces a change in resistance that is used in a bridge circuit to give a measurement of temperature. This temperature measurement, when combined with a measurement of local ambient temperature, gives an indication of the rate of fluid flow into the borehole. U.S. Patent 4,621,929 discloses a fiber optic thermal anemometer using a sensor element with temperature sensitive optical properties.

The present invention is an apparatus and method for monitoring the fluid flow from a producing well with a plurality of producing intervals. A cable that includes a number of fiber optic thermal anemometer sensors is deployed in the producing well with the sensors in the vicinity of the perforations in the casing or inlets from which fluid from the reservoirs enters the production casing. The present invention also provides temperature distribution along the heater cable length which information is utilized to control the operation of the heater cable.

SUMMARY OF THE INVENTION

The present invention provides a heater cable that may be deployed in a wellbore to elevate the temperature of the wellbore above the temperature of the surrounding fluid and the formation. One or more fiber optic strings are included in or are carried by the heater cable. The heater cable carrying the fiber optics is placed along the desired length of the wellbore. At least one fiber optic string measures temperature of the heater cable at a plurality of spaced apart locations. Another string may be utilized to determine the temperature of the wellbore. In one aspect of this invention, the heater cable is heated above the temperature of the wellbore. The fluid flowing from the formation to the wellbore lowers the temperature of the cable at the inflow locations. The fiber optic string provides measurements of the temperature along the heater cable. The fluid flow is determined from the temperature profile of the heater cable

provided by the fiber optic sensors. In another aspect of this invention, the temperature distribution along the heater cable is used to control the operation of the heater cable to maintain the elevated temperature within desired limits.

The heater cable may be selected turned on and turned off to provide only the desired amount of heat. This may be accomplished by selectively turning on and turning off the heater cable or by increasing and decreasing the electric power supplied as a function of the downhole measured temperatures.

BRIEF DESCRIPTION OF THE DRAWINGS

For detailed understanding of the present invention, references should be made to the following detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings, in which like elements have been given like numerals, wherein:

FIG. 1A shows a portion of a heater cable carrying fiber optic strings according to the present invention.

FIG. 1B shows the cable of **FIG. 1A** deployed in a producing borehole that penetrates a number of reservoirs.

FIG. 2 shows a heater cable deployed in a wellbore being controlled by

a control unit as a function of the temperature measurements provided by the fiber optic sensors in the cable.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1A shows a portion of a cable **10** according to one embodiment of the present invention. It includes a heater cable **20** that carries electrical current and is used as a source of heat by means of uniformly dispersed resistive elements within a portion of the cable (not shown). The cable also includes a pair of fibers **30a**, **30b** for carrying optical signals down the borehole and back up the borehole and for measuring temperature at spaced locations along the fibers.

FIG. 1B shows the cable **10** deployed in a producing borehole **50** that penetrates a number of reservoirs. For illustrative purposes, three producing intervals **40a**, **40b** and **40c** are shown. For illustrative purposes only, each of the three producing intervals is assumed to have a uniform temperature of T_0 . Further, each of the three producing intervals has a different rate of flow, denoted by Q_1 , Q_2 , Q_3 , of reservoir fluid into the producing well **50**. A plurality of fiber optic sensors, **60a**, **60b**, **60c**..... **60n** in the cable **10** make continuous measurements of temperature at the respective locations. To determine the flow rate from the various zones Q_1 - Q_3 , a control unit **60**

provides power to the heater cable 20, to cause it to heat the wellbore 50 to a temperature T_1 that is significantly higher than T_0 . The fluid flowing from the zones 40a-40e, which causes the temperature of the heater cable 20 to drop at the flow locations. Under these conditions, the greater the flow rate of fluid Q_i past a sensor, the greater the temperature of the sensor will drop from T_1 towards T_0 . Measurements of temperature of the sensor are used as an indication of the flow of the formation fluid into the wellbore 50.

The control unit 60 receives the signals from the fiber optic strings 30a-30b and can be programmed to calculate the fluid flow from each zone. A log such as shown by the resultant log 70 may be continuously displayed and recorded by the control unit 60. The log 70 shows a temperature profile along the well 50. An example of the affect on the temperature curve 80 of the flow from zones Q1-Q3 respectively is shown at locations 80a-80c.

Fig. 2 shows a heater cable 100 made according to the present invention, deployed or placed in a wellbore 110 having a casing 112. The cable 100 includes one or more fiber optic string 120 adapted to measure temperature at spaced apart locations T_1 - T_n along a segment or portion of the cable 100 shown by the dotted line. The heater cable 100 is adapted to heat any desired segment of the cable. For convenience, the heater cable herein is assumed to carry heating elements that heat the segment from T_1 - T_n . A power unit 130

supplies power to the heating element 111. A control unit 140 controls the power unit 130, and an optical energy and data unit 142.

The heater element 111 is heated to a predetermined temperature to enhance production flow to the surface. The fiber optic string continuously provides the temperature profile along the wellbore via sensor T1-Tn. If the temperature of the cable 100 in the wellbore is outside a predetermined norm, the control unit 140 adjusts the power to the cable 100 until the heater cable temperature provided by T1-Tn falls back in the desired limits. The control unit may be programmed to selectively turn on and turn off the heater cable to optimize the power consumption and to enhance the operating life of the heater cable.

The heater cable 100 may be deployed below an electrical submersible pump (ESP) when used as shown in Fig. 2 and also above the ESP. The temperature distribution T1-Tn along the heater cable is also useful in predicting heater cable 100 failures. It provides indication of hot spots in the heater cable and the efficiency of the cable corresponding to the input power.

Since the current supplied to the heater element 111 is the same, the heat generated by a uniform heater element will be uniform. The temperature distribution T1-Tn can thus provide indication of the quality of the heater cable's

110 performance.

While the foregoing disclosure is directed to the preferred embodiments of the invention, various modifications will be apparent to those skilled in the art. It is intended that all variations within the scope and spirit of the appended claims be embraced by the foregoing disclosure.

WHAT IS CLAIMED IS:

1. A method of determining flow of fluid from a formation into a wellbore, comprising:

providing a heater cable with a fiber optic string adapted to measure temperature at selected spaced apart locations along said heater cable;

placing said heater cable along a segment of said wellbore that is receiving fluid from adjacent formation;

heating the heater cable to a temperature above the temperature of the wellbore at said selected segment;

measuring a temperature profile along said heater cable by said fiber optic string; and

determining from said temperature profile flow of fluid from said formation into the wellbore.

2. The method of Claim 1 further comprising:

providing a control unit at the surface for receiving temperature measurements from said fiber optic string.

3. The method of Claim 2 further comprising:

providing a temperature log of said wellbore from said temperature measurements.

4. A method of controlling the operation of a heater cable deployed in a wellbore, said heater cable heating a segment of said wellbore to enhance production of fluids through the wellbore, said method comprising:

providing a heater cable with a fiber optic string adapted to measure temperatures at spaced apart locations along said heater cable;

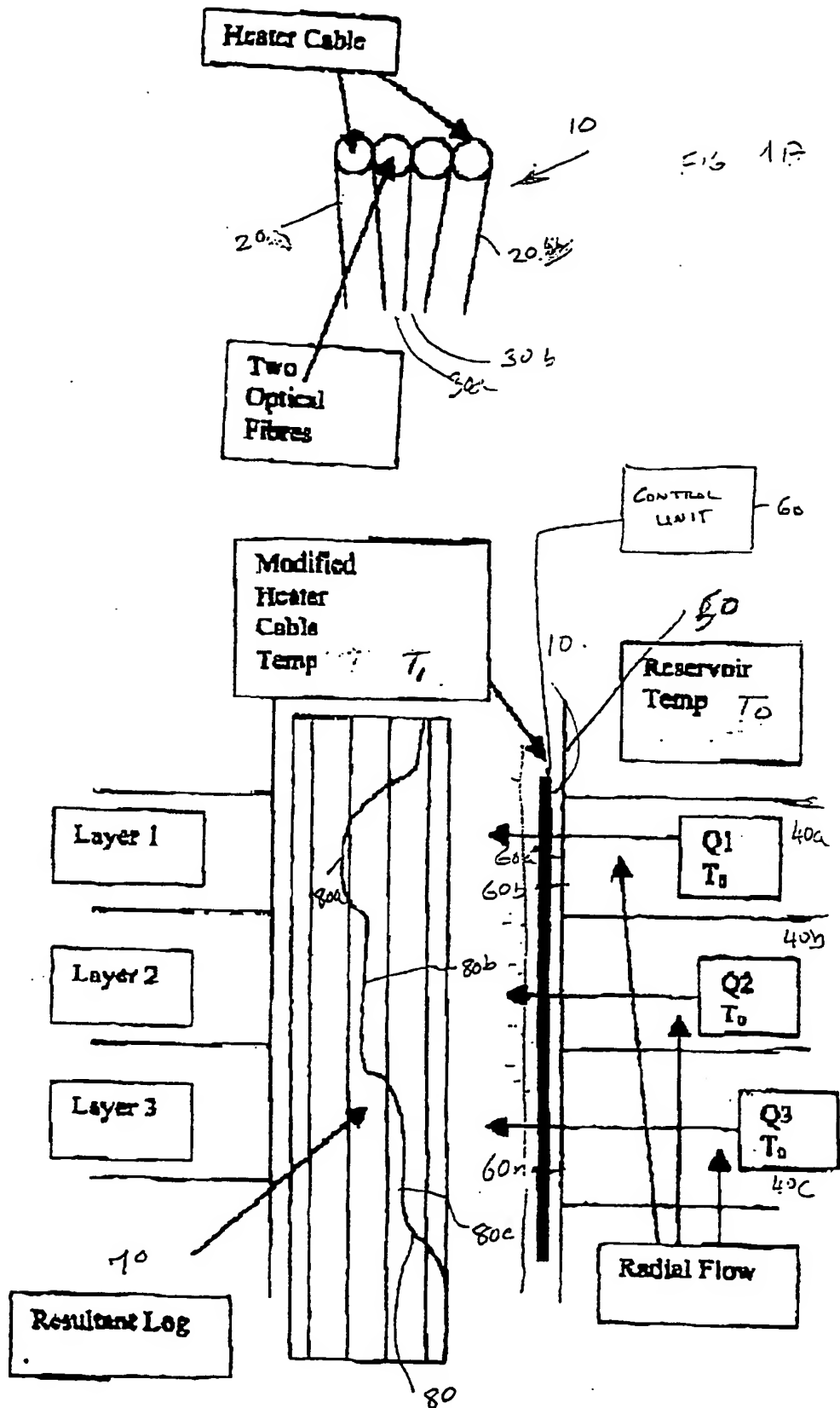
deploying said heater cable at a selected location in said wellbore;

providing power to said heater cable to heat the wellbore to a first temperature;

measuring temperature at selected locations by the fiber optic string; and

adjusting the power to the heater cable as a function of the temperature measurements.

5. The method of claim 4 further comprising providing a control unit at the surface, said control unit controlling the supply of power to the heater cable as a function of the temperature measurements.



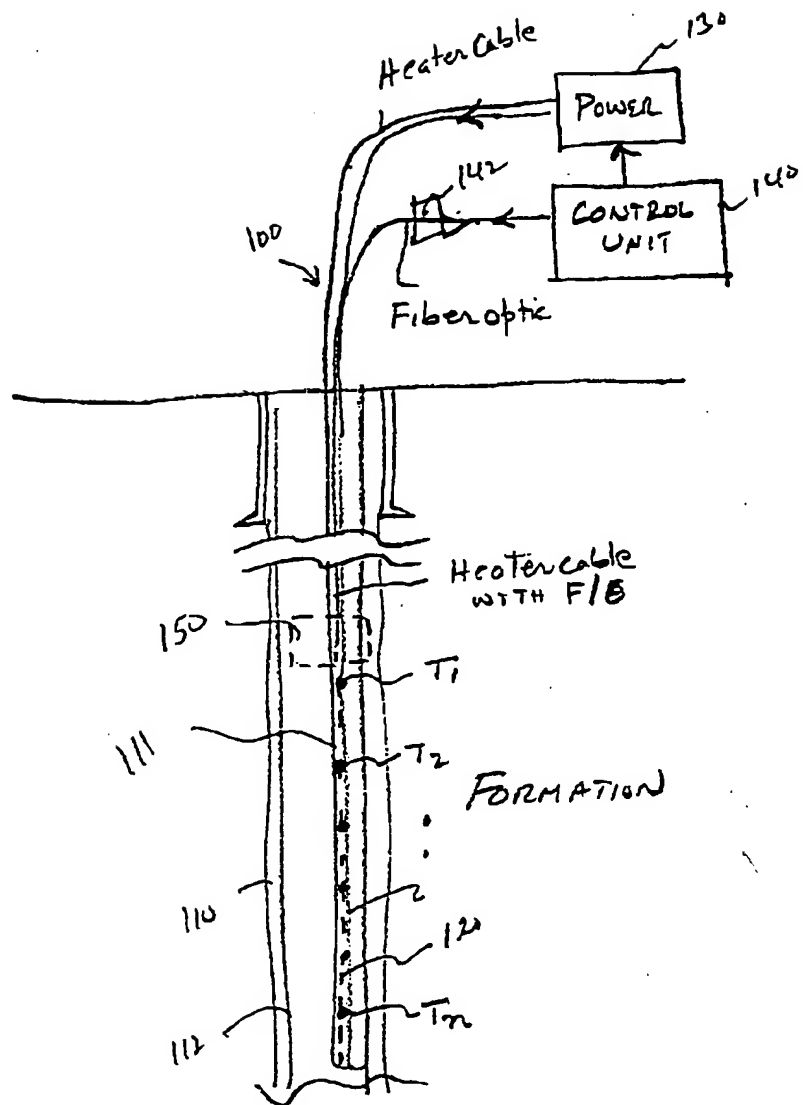


FIG 2

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 99/19781

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 E21B47/10 E21B36/04 E21B47/06 E21B47/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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E	WO 99 45235 A (SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ B.V.) 10 September 1999 (1999-09-10) page 5, line 18 -page 6, line 6 page 6, line 28 - line 29 claims 3,4 page 4, line 14 - line 18 ---	1-5
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☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

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- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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- * & * document member of the same patent family

Date of the actual completion of the international search

5 January 2000

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 99/19781

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INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 99/19781

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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A	US 4 621 929 A (PHILLIPS) 11 November 1986 (1986-11-11) cited in the application abstract -----	1,4